BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. **1** illustrates a cross section of a top-emitter OLED device having a scattering layer according to one embodiment of the present invention;

[0022] FIGS. **2**A and **2**B illustrate cross sections of scattering layers according to various embodiments of the present invention;

[0023] FIG. **3** is a graph depicting the performance of various scattering layers in an OLED;

[0024] FIG. **4** is a flow diagram illustrating a method of making a device according to the present invention;

[0025] FIG. **5** illustrates a cross section of a prior-art top-emitter OLED device; and

[0026] FIG. **6** illustrates a cross section of a prior-art top-emitter OLED device having a scattering layer.

[0027] It will be understood that the figures are not to scale since the individual layers are too thin and the thickness differences of various layers too great to permit depiction to scale.

DETAILED DESCRIPTION OF THE INVENTION

[0028] Referring to FIG. **1**, in accordance with one embodiment of the present invention, a top-emitting organic light-emitting diode (OLED) device, comprises a substrate **10**; an OLED comprising a reflective electrode **12** formed on the substrate **10**; one-or-more layers **14** of organic light-emitting material formed over the reflective electrode **12**; and a transparent electrode **16** formed over the one-or-more layers **14** of organic light-emitting material; a light-scattering layer **22** having a rough surface formed over and in contact with the OLED; a cover **20** affixed to the substrate **10** forming a gap **18** between the cover **20** and the light scattering layer **22**; and wherein the gap **18** is a vacuum or the gap **18** is filled with a relatively low-refractive index gas and the light-scattering layer **22** comprises a plurality of relatively high-refractive index light-scattering transparent particles **70** projecting into the gap **18** without contacting the cover **20** and further comprising an adhesive binder in contact with at least some of the light-scattering particles **70** to adhere the light-scattering particles **70** to the OLED. Transparent particles **70** are sufficiently transparent to pass at least a portion of light emitted by organic layers **14**. An OLED-protective layer **24** may be formed over the transparent electrode **16** to protect the OLED. Preferably, when employed, the OLED protective layer **24** has an optical index equal to or greater than the index of the organic layers **14**. As used herein, a rough surface is variable, irregular, and preferably discontinuous. A relatively low refractive index is one that is lower than the organic layers **14**, transparent electrode **16**, and cover **20**, and, preferably has a refractive index less than 1.1. A relatively high refractive index is one that is higher than the refractive index of the material in the gap so as to cause significant refraction and scattering at the interface with the gap **18**, and preferably is higher than the refractive index of the organic layers **14** or transparent electrode **16** and, accordingly more preferably has a refractive index greater than 1.8. If the gap **18** includes a gas, it may be nitrogen, argon, helium, or air and is preferably inert and non-reactive to the various OLED layers and light-scattering layer **22**.

[0029] Referring to FIGS. **2**A and **2**B, the light-scattering layer **22** is shown in greater detail with adhesive binder **74** adhering the light-scattering particles **70** to the transparent electrode **16** or OLED-protective layer **24**. As shown in FIG. **2**A, a minimal amount of adhesive binder **74** is employed to adhere the light-scattering particles **70** to the OLED. As shown in FIG. **2**B, a greater quantity of adhesive binder **74** is employed to adhere the light-scattering particles **70** to the OLED such that some of the light-scattering particles **71** are completely immersed in the adhesive binder **74**. However, according to the present invention, in all cases at least a fraction of, and preferably most of, the light-scattering particles **70** project into the gap **18** without contacting the cover **20**. When substantial amounts of adhesive binder **74** is used, the light scattering ability of the light-scattering particles **71** is superior if the index of refraction of the light scattering particles is substantially (>0.2) higher than the index of refraction of the adhesive binder.

[0030] Referring back to FIG. **1**, it is helpful for the light-scattering layer to provide effective scattering over a broad range of frequencies. In some OLED device embodiments, the organic layers **14** emit white light and employ patterned color filters **40**R, **40**G, and **40**B corresponding in position to the patterned reflective electrode **12** to provide a full-color display having colored sub-pixels **50**R, **50**G, and **50**B. Even if the organic layers **14** are patterned with different organic materials that emit different colors of light, for example red, green, and blue, it is useful and inexpensive to employ and coat a single, unpatterned scattering layer **22** over the OLED to extract trapped light of all frequencies from every sub-pixel of whatever color. As described herein, any color filters **40** are considered to be part of the cover **20** and do not contact the light-scattering particles **70**.

[0031] In operation an active-matrix OLED device such as that depicted in FIG. **1** employs thin-film electronic components **30** to provide a current through the patterned reflective electrode **12** and transparent, unpatterned electrode **16**. Planarization insulating layers **32** and insulating layer **34** protect the electronic components and prevent patterned electrodes **12** from shorting to each other and thereby form light-emissive areas **50**R, **50**G, and **50**B. When a current is provided between the electrodes, one or more organic layers **14** emit light. The light is emitted in all directions so that some light will be emitted toward the transparent electrode **16** and scattering layer **22**, be scattered into the gap **18** and thence through the cover **20** out of the device. Likewise, some light will be emitted toward the reflective electrode **12**, be reflected back toward the transparent electrode **16** and scattering layer **22**, and then be scattered into the gap **18** and thence through the cover **20** out of the device. However, some fraction of the light will waveguide in the relatively high-index organic layers **14** and transparent electrode **16**. This normally trapped light will also be scattered because the scattering layer **22** is optically coupled to the OLED, and may then pass into the gap **18**, through the cover **20**, and out of the OLED.

[0032] However, some fraction of the light will be scattered back into the OLED. This reflected light will again pass through transparent electrode **16** and organic layers **14**, be reflected from reflective electrode **12**, pass through the organic layers **14** and transparent electrode **16** a second time, and be-rescattered. Some of the re-scattered light will pass into the gap **18** and through the cover **20**. The light that is